PROMOTION OF INTEGRATED WATER RESOURCES MANAGEMENT PRACTICES IN THE CONTEXT OF CLIMATE CHANGE AND VARIABILITY IN MALAWI A CASE STUDY OF LAKE CHILWA BASIN

Cosmo Ngongondo[1], Samson M.I. Sajidu, Russel C.G. Chidya, Wapulumuka O. Mulwafu

[1]Chancellor College, University of Malawi, P.O. Box 280 Zomba, Malawi; cngongondo@cc.ac.mw

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Abstract

Integrated Water Resources Management (IWRM) has been widely accepted as the most effective approach for the management of water resources, and the ecosystem goods (EG) and services (ES) derived from them. In Malawi and other developing countries, there has been a low degree of implementation of IWRM practices in order to optimize socio-economic and environmental benefits from EG and ES in response to climate change effects. This study examined the existing capacities and challenges facing Malawi in terms of implementation of ecosystem based approaches for effective IWRM practices under changing climatic conditions using the Lake Chilwa basin ecosystem as a case study. Both qualitative and quantitative methods were used to collect and to analyse data. The results showed that most organisations have no existing policies, laws, practices, and institutional structures to support IWRM practices. The study also revealed lack of political will in implementation of IWRM practices, internally contradicting policies, weak laws, and low funding. As result, catchment degradation is evidenced by the poor results of physicochemical characteristics of surface water in the area attributed to increased nutrient loading and anthropogenic activities. The lake registered low water levels and increased Total Dissolve Solids (TDS) (2,000 mg/L), high Electrical Conductivity (EC) levels (3,998 µS/cm), and surface water temperatures (28.5-41.5 °C). These are indications of a highly committed ecosystem with many activities competing for the EG and ES in the catchment. The hydrometeorological analysis showed clearly consistent downward insignificant trends in basin wide rainfall but significant decreasing trends in river discharge and Lake Chilwa levels that can be attributed to anthropogenic activities. This calls for a review of existing policies and coordinated efforts in management of water resources and ecosystems to mitigate the effects of climate change and variability.

1 Introduction

Water demand is a major concern in Southern Africa because of increasing human population and the associated demands for water resources. Many people in the developing world, usually in rural areas, do not have safe water supply [1]. Climate change and its variability further pose a very serious challenge in water resources management to an already critical situation and, therefore, require serious consideration from a holistic view. Until lately, in many developing countries like Malawi water has been managed by various institutions (public, private, NGOs, etc.) with each operating independently from each other [2]. This approach may be only convenient in a world, where there are no constraints on the resources and the ecosystems responsible for sustaining the resources. However, such an approach is not appropriate in many developing countries, where water is an increasingly scarce resource such that ecosystems are always under extreme pressures to meet water demands from numerous water using activities. Integrated Water Resources Management (IWRM) has been widely accepted as the most effective approach for the management of water resources, and the ecosystem goods (EG) and services (ES) derived from them. The basis of IWRM identifies different uses of water as co-dependent such that the goal must be to manage and to develop water resources in a holistic and sustainable manner. Integrated management means that all different aspects of water resources are considered together, ensuring optimal social benefits of water resources uses as well as to the protection of human health and the environment as a whole [3]. In Malawi, there has been a low level of understanding of IWRM practices in response to climate change effects for sustainable land and water resources management. This study, therefore, aims to promote understanding, collaboration, capacity building, and implementation of IWRM practices for sustainable national development under changing climatic conditions. Climate change and climate variability can be mitigated by appropriate integrated water resources management policies and adaptation measures, which reduce vulnerability for both natural and human systems [4].

1.2 Study Area and Methodology

2.1. Description of the study area

The study uses a case of Lake Chilwa basin located in Malawi in Southern Africa [5]. Lake Chilwa, a tropical endorheic lake, is Malawi's second largest lake after Lake Malawi. The lake was designated a wetland of international importance and ratified by the Ramsar Convention in 1997 [6]. The Lake Chilwa ecosystem is very important to the economy of Malawi as it provides a large proportion (25-30%) of fish [6], and large population of the people in the catchment are either smallholder farmers or fishermen. The lake has an open water area of approximately 678 km^2, which is surrounded by about 600 km^2 of Typha swamps, 390 km^2 of marshes, and 580 km^2 of seasonally inundated grassland of floodplain (Lake Chilwa Wetland Project 1999). In "normal" years, open water can cover about 1,500 km^2; one-third of this is swamp and marshes, and one-third is floodplain. The entire catchment area is 8,349 km^2, of which 5,669 km^2 is in Malawi and the rest in Mozambique.

2.2 Data collection and analysis

The research used both quantitative and qualitative methods for data collection. Qualitative data were collected using the following tools: literature review and key informant interviews based on structured questionnaire. Rainfall data for 8 stations within the catchment for the period 1948 to 2011 were collected from the Malawi Department of Climate Change and Meteorological Services. Temperature, potential and actual evapotranspiration trends at Chancellor College, Makoka and Ntaja stations were adopted [7] in their study on the water balance of Malawi from 1971-2001. River discharge data for 8 gauging stations and Lake Chilwa water levels (Fig. 1) were sourced from the Ministry of Water Development and Irrigation, Surface Water section. These were analysed for trends using the Mann-Kendall test and linear regression.

A total of 11 sites were purposively selected and sampled along the rivers in the study area (Likangala, Domasi, and Thondwe Rivers, and Lake Chilwa) (Figure 1). Each site was denoted as a sampling point (S). As a baseline survey, water samples were then collected at the beginning of the rainy season in December 2012 from the selected sites to monitor and to assess the surface water quality. At the time of the field sampling, Lake Chilwa levels were showing a decreasing trend over a 2 year's period, normally associated with a complete drying of the lake due to low rainfall in the catchment. The samples were collected in triplicate using 1 L plastic bottles, transported and preserved in accordance with standard methods [8, 9]. The water samples were analyzed for various physicochemical parameters at the Chemistry Department of the Chancellor College.

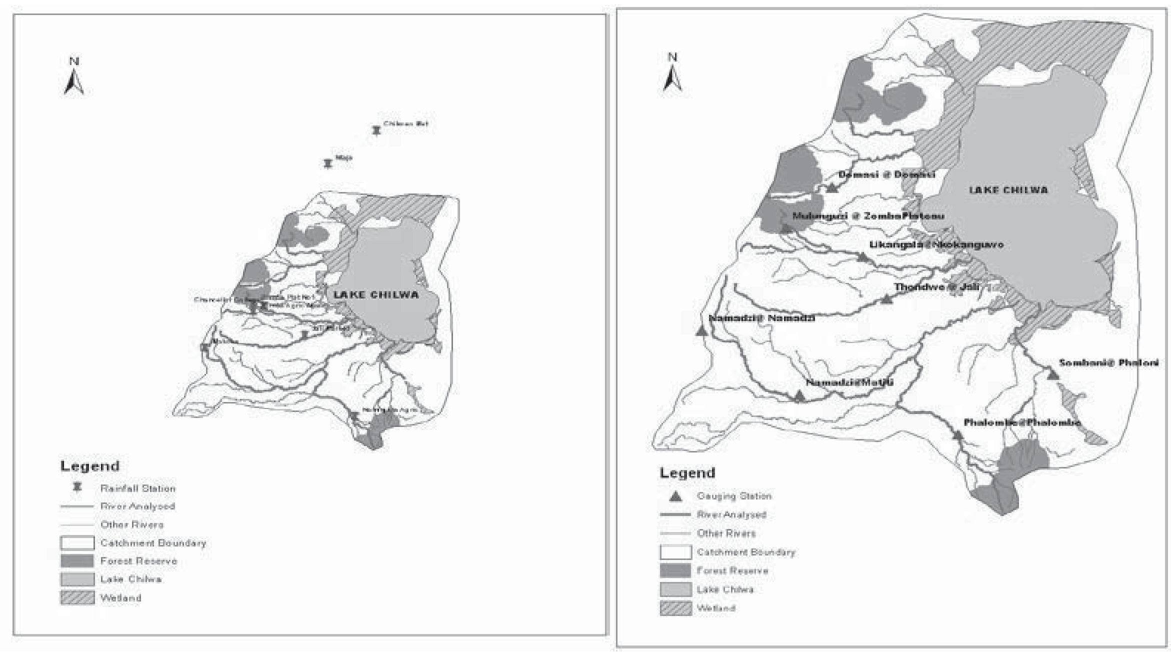

Figure 1: Experimental stations at the Lake Chilwa Basin

3 Results and Discussions

3.1. Policies, laws, practices, and institutional structures supporting or limiting implementation of IWRM in Malawi

IWRM broadly encompasses elements of good water governance such as effective coordination, participation, equity, sustainable development, and inclusiveness. Our results show that the concept of IWRM has so far been well publicized in Malawi as all the stakeholders that were consulted were aware of the concept. It was also very clear that there have been a number of activities and initiatives that have helped to raise public awareness of the benefits of IWRM, the most significant one being the development of a national IWRM Plan in 2008. Moreover, the National Water Policy (2005) considers the IWRM as a useful strategy for effective and sustainable management of water resources. Thus, although it is no longer a new concept in the country, it remains an idea that is still not well understood by some of the stakeholders.

Yet, many of the institutions interviewed consider IWRM useful for achieving socio-economic development because it addresses issues of livelihoods. It also promotes stakeholder participation, which is essential for climate change adaptation and mitigation. Results from the study show that most of the key respondents representing institutions in the basin observed that their institutions lack specific policies, laws and institutional arrangements to support IWRM and climate change. It was further highlighted that there are existing law and policy instruments having relevance to IWRM but are currently fragmented. The instruments cited to have some relevance included the National Water Policy of 2005, Forestry Policy of 1996, Forestry Act of 1997, National Adaptation Plan of Action, National Environmental Policy of 1996, National Environmental Management Act of 1997, and the Malawi Growth and Development Strategy. It was further pointed out that several challenges confront the implementation of IWRM to mitigate the effects of climate change. In the first place, policies need to be reviewed so that they are in line with IWRM principles and also provide for better coordination.

The second challenge relates to lack of adequate capacity (human and financial) to implement IWRM. Most state funded institutions often do not have the requisite staff or funding to carry out IWRM activities. Third, there was lack of a clear relationship between IWRM and climate change, and that the media in the country do not adequately cover these issues.

Respondents were also asked to explain problems being experienced when using existing frameworks to promote IWRM practices in the context of climate change. Most of them argued that the current framework was either weak or inadequate, and hence they need for revision. It was apparent that the present sectoral organization and nature of government agencies are major roots to the coordination challenges. Each of the consulted institutions and key informants came up with specific strategies that they felt could be used to promote IWRM under changing climatic conditions. The general ones that were commonly mentioned are:

- Development of formal partnerships to undertake climate change research,
- Recruitment and training of IWRM staff to work at local level,
- Strengthening the networking and sharing of best practices in IWRM,
- Capacity building in data collection, monitoring and research,
- Increased allocation of resources, and
- Support the review of relevant policies, laws, guidelines and manuals.

While national institutions are undoubtedly important in the promotion of IWRM practices, local communities are equally central to the success of any interventions. The study, therefore, sought views on ways, in which the capacity of such local stakeholders could be adapted to promote IWRM practices. The results show that local people did not know the specific technical concepts of IWRM and climate change but have some capacity, which could be tapped and enhanced.

The study also found from the respondents that climate change and variability have an influence on the activities of their communities and institutions, albeit indirectly in some cases for the institutions, since water is the main driving force for agricultural production and fisheries development in the Lake Chilwa basin ecosystem, changes in rainfall patterns affect the livelihoods of people in the study area in many ways. First, decrease in rainfall, which in turn affects river flows, has in some cases forced residents to change the sources of water supply from natural surface water to the increased use of boreholes.

3.2 Hydrometeorological Changes

Table 1 shows the monthly and annual average rainfall for the 8 rainfall stations and Figure 2 the annual rainfall climatology at selected stations within the catchment.

Table 1: Annual average rainfall (mm/year) and monthly average rainfall (mm/month)

Station	Annual Mean (mm)	Stdv (mm)	CV (%)	Monthly Mean (mm)
Chanco	1,373	351	25.6	115
Ntaja	935	200	21.4	79.0
Chikweo	1,047	270	25.8	89.0
Naminjiwa	876	234	26.7	81.0
Zomba RTC	1,124	372	33.1	91.0
Makoka	1,023	259	25.3	85.0
ZombaP	1,879	842	44.8	NA
Zaone	768	429	55.9	NA

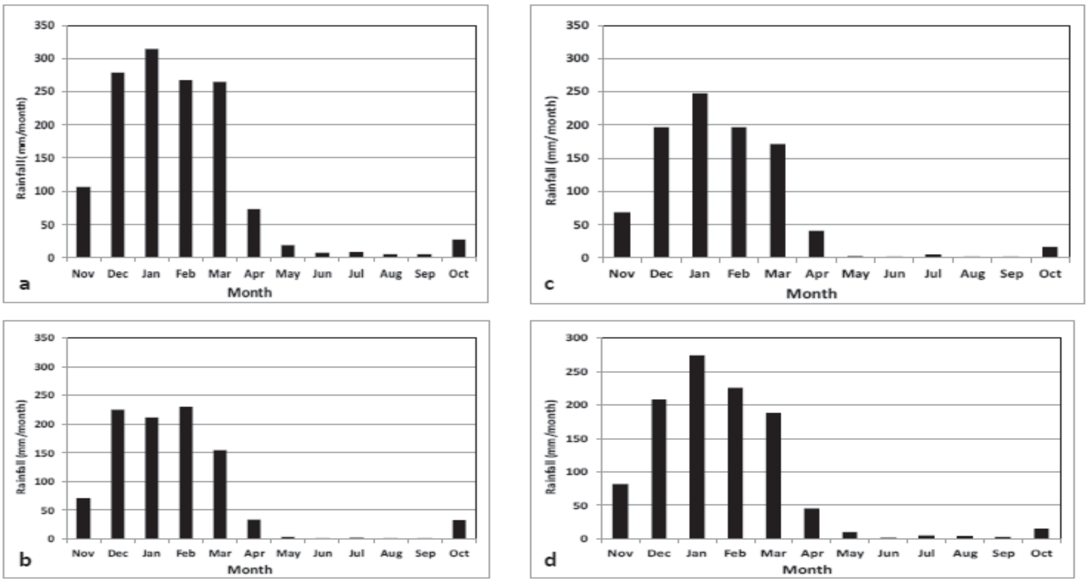

Figure 2: Annual rainfall regime at (a) Chancellor College; (b) Naminjiwa; (c) Ntaja; and (d) Chikweo stations

Annual mean rainfall varied spatially with the stations located at higher altitudes (Chancellor College, Zomba Residential Training Centre, Zomba Plateau, and Chikweo) having higher annual totals and monthly averages. This is a clear indication of topographic influences on spatial variation in rainfall. The monthly average annual rainfall over the catchment from these six stations is, therefore, estimated at 90 mm/month, and the total annual average rainfall for the catchment is estimated at 1,128 mm, with a standard deviation of 369 mm and a coefficient of variability of 32.3%. This means that rainfall in the basin is highly variable between years, showing both extremes of high and low rainfall, and is in agreement with [13], who found an increase in rainfall variability in Malawi.

The results of annual temporal rainfall variation in the Lake Chilwa catchment area are shown in Table 2. It can be observed that Chancellor College, Ntaja, Makoka, and Zomba Plateau experienced negative trends in rainfall, none of which was statistically significant. On the other hand, Chikweo, Naminjiwa, Zomba RTC, and Zaone had positive trends that were not statistically significant. The annual rainfall trends suggest that annual rainfall in the lake Chilwa Basin is, therefore, stationary since none of the trends are significant. At seasonal timescales, a predominance of negative trends can be observed basin-wide, with the exception of Chikweo, which had a positive trend that was not statistically significant. Makoka and Chancellor College had negative trends that were statistically significant. In the rainy season, Chancellor College and Ntaja had negative trends that were not statistically significant, and the rest of the stations had positive trends that were not statistically significant. The non-significance of the seasonal trends is further indication of the stationarity of the rainfall in the basin and is in agreement with the annual rainfall series.

Table 2: Annual and seasonal rainfall MK trends and slopes (mm/year)

Station		MK Trends		Slopes		
	Annual	Dry	Wet	Annual	Dry	Wet
Chanco	-1.64	-2.69	-0.99	-6.62	-0.98	-2.89
Ntaja	-1.13	-1.13	-0.53	-2.14	-0.61	-1.49
Chikweo	0.7	0.11	0.26	7.46	-0.27	0.43
Naminjiwa	1.24	-0.49	0.87	0.53	-0.87	0.43
Zomba RTC	0.93	-1.09	1.04	34.4	-1.76	38.6
Makoka	-0.01	-2.1	0.8	1.34	-0.57	2.91
Zomba Plateau	-0.68	NA	NA	-27.2	NA	NA
Zaone	0.61	NA	NA	11.5	NA	NA

In their study on the water balance trends over Malawi during 1971-2001, [10] analyzed changes in water balance components over Malawi with a special focus in rainfall, temperature, potential (PET) and actual (AET) evapo-transpiration. The decreasing annual rainfall signal over Malawi in that study agrees with results from this study over Lake Chilwa, and both are not statistically significant. We extract from that study trends in annual mean temperature, potential and actual evapo-transpiration for stations located in the Lake Chilwa Basin as shown in Table 3.

Table 3: Trends in annual temperature, potential (AET) and actual evapo-transpiration (PET)

Station	MK Trends			Slopes		
	Temperature	PET	AET	Temperature	PET	AET
Chanco	3.16	3.02	-1.96	0.110	0.08	-0.20
Makoka	3.41	3.16	-1.00	0.021	0.11	-0.20
Ntaja	2.39	1.13	-1.50	0.035	0.70	-2.79

From Table 3, it is noted that temperature at the 3 stations within the Lake Chilwa Basin, namely Chancellor College, Makoka and Ntaja increased with statistical significance with respective linear regression slopes of temperature against time of 0.110 ^{o}C/year, 0.021 ^{o}C/year, and 0.035 ^{o}C/year. Potential evapo-transpiration, which represents the upper limit of evapo-transpiration, when there are no moisture supply and energy limitations in an area, also increased with statistical significance following the temperature trend and had annual slopes of 0.08 mm/year, 0.11 mm/year, 0.70 mm/year, respectively. Actual evapo-transpiration (AET), on the other hand, decreased at all the stations but without statistical significance at α=0.05 level. As discussed by [10], such a decrease in AET coupled with the decreases in rainfall is an indication of increased aridity in the catchment area, despite the observed stationary in rainfall amounts.

3.3. Trends in lake levels and discharge

Table 4 shows the trends and slopes of mean annual lake level and discharge for the period 1958-2011. MK trends show that annual lake levels changed with statistical significance. For the rivers, all but Sombani had negative trends, and Mulunguzi had a statistically significant trend. The positive trend at Sombani was not statistically significant.

Table 4: MK trends for Annual lake levels (m/year) and mean annual river discharge (m^3/year)

Station	**MK Trend**	**Slope**
Level	-3.01	-0.07
Domasi	-1.09	-0.01
Sombani	1.00	0.10
Phalombe	-0.12	0.02
Likangala	-1.84	-0.02
Thondwe	-1.63	-0.03
Namadzi at Matiti	-1.36	-0.02
Namadzi at Namadzi	-1.40	0.00
Mulunguzi	-2.80	-0.01

Evaluation of cross-correlation coefficients between annual Lake Chilwa levels and rainfall shows weak correlations, with only Ntaja and Zomba plateau stations having moderate correlation. The same situation was prevalent with correlations between annual lake levels and river discharge, with only Thondwe and Sombani having moderate correlations. At annual time scale, the levels of correlations of lake levels and the inflows from the various rivers were expected to be very strong. On the other hand, low correlation between lake levels and rainfall can be attributed to the delayed response of the lake levels to rainfall input, as catchment processes are also involved in transforming rainfall into runoff, which is subsequently routed to river channels down to the lake. It can, therefore, be postulated that the lake response to inflows is being affected by a combination of factors including land use in the catchment area.

3.4 Climate change impacts on water quality

This section presents results of potential climate change impacts on water quality in the Lake Chilwa basin. The study was, however, restricted by the lack of historical water quality monitoring data, which are very scanty in many developing countries like Malawi. Potential impacts of climate change on surface water temperature include changes in air temperature, which could affect water temperature due to heat exchange with the atmosphere. Increasing water temperature will affect the rates of chemical and bacteriological reactions in water resulting in consequent deterioration of water quality and status of water ecology. Enhanced growth rates of algal blooms in freshwater bodies are one such example of specific impact. In general, the higher the air temperature, the higher the water temperatures with higher rates of chemical reactions, and studies have shown that such correlation is strong particularly for rivers and shallow lakes [8]. Projected changes in air temperature often result in water temperature changing by 50-70% [9]. Due to lack of regular water temperature monitoring in the Lake Chilwa Basin, there are insufficient data to be able to indicate a general trend of water temperature with regard to climate change or variability. However, air temperature data obtained at Chancellor College (within the Lake Chilwa Basin) between 1982 and 2007 showed an increasing statistically significant trend [7]. Air temperature is projected to increase by about 3.26 °C by 2070 resulting in a surface-water temperature increase in the Lake Chilwa Basin by around 1.63-2.28 °C with clear seasonal dependency as has been the case.

In addition, increased water temperatures are expected to result in increased nutrient loads into rivers and lakes. For instance, the higher the temperature, the greater is the release of phosphorous from sediments. Higher temperatures enhance mineralization rates of soil organic matter resulting in increased nitrate leaching [10]. There are no time series data for nutrients in surface water of the Lake Chilwa Basin except for a few scattered spatial and temporal studies. Water samples collected by the Ministry of Irrigation and Water Development for Ruo, Phalombe, Thuchira and Domasi Rivers at specified locations within the basin contained insignificant concentrations (below detection limit) of nitrates. Likangala River contained nitrates (3.6 – 40 ppm) and phosphates (0 – 10.7 ppm) with strong seasonality in the concentrations [14-17]. Increased levels of nutrients in some parts of the basin had been attributed to agricultural activities or from sewage treatment works. Our data collected in the rainy season (December 2012) as part of baseline data gathering for Thondwe, Likangala and Domasi Rivers are shown in Table 5.

Table 5: A summary of physicochemical characteristics of surface water in some main inflow rivers of Lake Chilwa and the Lake measured in Dec 2012

Site	pH	EC (µS/cm)	TDS (mg/L)	Water Temp (°C)	Turbidity (NTU)	HCO_{3-} (mg/L)	CO_3^{2-} (mg/L)	SO_4^{2-} (mg/L)	PO_4^{3-} (mg/L)	Cl- (mg/L)	Hardness (mg/L CaCO3)
Thondwe River	6.57 - 6.70	63.0-204	31.5-91.5	21.0-25.4	11.6-563	18.3-186	0	3.12-30.7	0.72-18.4	1.85-11.2	28.9-89
Likangala River	6.83 - 7.80	57.0-138	27.7-62.0	21.6-29.4	44.8-447	55.1-104	0	3.38-12.7	1.71-6.50	16.7-26.6	42.0-56.7
Lake Chilwa	7.10 - 10.7	303-3,998	152-2,000	28.5-41.5	1.83-270	143-1,031	0-694	<1-7.31	2.26-5.72	103-357	27.6-64.4
Domasi River	7.03 - 8.80	26.0-70.0	10.5-34.7	267-26.8	18.9-66.2	45.5-103	0	<1 – 2.22	1.24-2.70	57.2-77.3	14.8-37.4

Further analysis of the water quality data also shows that Lake Chilwa is highly alkaline (pH up to 10.7 and CO_3^{2-} up to 694 mg/L). The lake also acts as a sink of pollutants as shown by high levels of total dissolved solids (TDS up to 2,000 mg/L) and electrical conductivity (EC up to 3,998 µS/cm at the harbor).

Despite lack of data on the past trends of nutrients in the surface water of the Lake Chilwa Basin, the predicted increase in water temperature will most likely result in increasing nitrate concentrations due to increased soil mineralization. Additionally, rise in water temperature enhances rates of algal growth, especially of cyanobacteria. Predicted reduced river flow rates in summer will result in increased residence times of water in some reaches and reduced load dilution capacity, hence increased pollutant concentrations; consequently, increasing potential growth of algae and also enhancing settling rates of sediments. This subsequently reduces water turbidity and improves light penetration that promotes growth of algae. In addition, increase of temperature and low rainfall are expected to decrease dissolved oxygen (DO) concentrations. Increased nutrient levels and temperature may also increase respiration; consequently reducing DO concentrations [13]. Previous studies on the Lake Chilwa basin have indicated good levels of DO (above 5 ppm) in most water bodies for effective support of diverse aquatic population except at specific points (below 5 ppm), where there are intrusions of sewerage matter with visible algal blooming, such as on Likangala River. Although time series data on DO concentrations are not available for prediction of future trends, the higher forecasted temperatures combined with increased nutrient loading are likely to result in decreased DO in rivers and the lake due to decreased oxygen solubility and increased respiration.

Very limited studies have been carried on climate change impacts on toxic substances in surface water [25]. Depending on the nature of their hydrolysis and degradation processes most toxic substances tend to attach to other particles and settle on the bottom of water bodies. Increasing temperature will thus be of direct impact on volatile compounds such as organic pollutants and mercury. There are virtually no reported data on concentrations of toxic substances such as pesticides and heavy metals in the Lake Chilwa basin except for very limited studies indicating concentrations of zinc (0 – 0.14 ppm), lead (0 – 0.71 ppm), chromium (0 – 0.39 ppm), and cadmium (0 – 0.05 ppm) in Likangala River [17]. All these processes would result in changes in ecosystem functioning.

4 Conclusion and Recommendations

The Lake Chirwa Basin is a very important ecosystem that provides critical goods and services for livelihoods of its riparian communities. The sustainability of its ecological functioning, however, faces various challenges, including those related to climate change and to water resources management. IWRM approaches have been identified as key to addressing some of these challenges. The study has revealed that although IWRM principles are fairly understood by various sectors in the basin, they are not adequately promoted due to different reasons such as lack of specialized media reporters on IWRM and climate change issues leading to poor information dissemination, lack of funding, sector-based organization of government agencies and natural resources management with limited collaboration, poor catchment management practice, and lack of partnerships among diverse institutions and key stakeholders. This calls for a review of existing policies in water and its related resources, and coordinated efforts in the management of water resources to mitigate the effects of climate change and variability.

The findings of this study have also shown varying trends in some physicochemical parameters attributed to climate change and other various pressures such as variation in rainfall pattern, temperatures, seasons, waste upload into water bodies, and geology of the basin. Although there is lack of data of water quality time series for proper prediction of climate change impacts in the Lake Chilwa basin, the increasing air temperature data is likely to result in an increase of surface water temperature (in rivers and the lake) by about 1.6 ^{o}C to 2.8 ^{o}C by 2070. This in turn may result in other problems such as reduced dissolved oxygen, increased nutrient loading and eutrophication, and increased volatile toxic compounds. The hydrometeorological analysis showed clear and consistent downward but statistically insignificant trends in basin wide rainfall, river discharge, and Lake Chilwa levels. However, only the Lake Chilwa levels had trends with statistical significance, and this suggest additional forcing to the climate signal. This demonstrates a need for investigating land use cover change and other anthropogenic activities in the basin.

These water resources management and climate change related challenges have an overall influence on the ecological functioning of the Lake Chilwa basin, largely threatening its ability to provide for current and future generations. Water resources managers in the basin, therefore, need to address these impacts by, among other measures, reducing diffuse pollution particularly by agricultural measures and river restoration activities such as tree planting on the river banks.

There is also need to enhance water resources and quality monitoring activities in order to understand current climate change impacts in the basin. Scientific studies such as paleo-limnological analyses of sediments may also help to create a long term water quality dataset in the basin.

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SEDIMENTS REACTIVITY RELATIVE TO Cd, Pb AND Zn IN ARTIFICIAL LAGOON WATER

Massabalo Ayah[1], Malgorzata Grybos[2], Ibrahim Tchakala[1], Lallébila Tampo[1], Venyo K. Akpataku[1], Moctar L. Bawa[1], Gbandi Djaneye-Boundjou[1], Hubert Bril[2]

[1]Laboratoire de Chimie des Eaux, Faculté des Sciences, Université de Lomé (LCE-FDS/UL), P.O. Box 1515, Lomé-Togo; a8yann@hotmail.com

[2]Groupement de Recherche Eau, Sol et Environnement, Faculté des Sciences et Techniques, Université de Limoges (France) EA 4330, 123 Avenue Albert Thomas 87060 Limoges Cedex, France

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Abstract
Sediments samples were collected to study their reactivity relative to Cd, Pb and Zn in the lagoon system of Lomé (Togo). Batch adsorption experiments were performed on four different sediments in artificial lagoon water for three ranges of concentrations of Cd, Pb and Zn, and desorption tests by a molar solution of ammonium acetate (1M). The results made it possible to demonstrate an adsorption capacity of almost 100% of Cd, Pb, and Zn for the ranges applied. The adsorption rates are higher in Equilibrium Channel (Cm) for Cd and Pb. Zn adsorbs more on the sediments of Bè Lake (Bm). The results of desorption tests showed low rates according to the metals. The desorption percentages were important for highest concentration, i.e., 44% Cd in sediments of Equilibrium Channel (Cm), 89% Pb in sediments of lake Bè (Bm), and 93% Zn for the sediments of West Lake (Om). These results confirmed the role of total organic matter, grain size, and mineralogy in promoting the capacity of sediment adsorption. However, the stability of trace metals in the sediments depends on environmental conditions like pH and Eh, which may cause their bioavailability in Lomé lagoon system.

1 Introduction
In aquatic environments, biogeochemical conditions can facilitate an exchange between the particulate and dissolved phases leading to the distribution of trace metals in the various compartments of a hydrosystem [1, 2]. The accumulation of these trace metals (TM) in sediments has become a concern in the deterioration of the quality of aquatic resources [3, 4, 5]. Natural and/or anthropogenic origins of trace metals are not all equally hazardous due to their physico-chemical properties and very variable according to the environmental conditions [6, 7, 8]. The mechanisms of remobilization of TM in lagoon hydrosystems sediments are still poorly under-stood, despite numerous experiments carried out by several authors [1, 2]. In the case of the Lomé lagoon system, most of the work was concerned with the overall content of trace metals such as Cd, Pb and Zn in the sediments of this hydrosystem [9, 10, 11, 12]. Indeed, the remobilization experiments of metal contaminants consist of estimating the risk of the bioavailability of trace

metals in hydrosystems. In view of what happens in sediments concerning the release of metal contaminants, a large number of parameters are likely to be taken into account during laboratory experiments, in particular, the mineralogical composition of the sediment (carrier phases), the time, and the pH change [1, 13-15].

The objective of this study was to evaluate the risk of pollution of Lomé lagoon system fed by rainwater and urban runoff, and was particularly aimed at highlighting the water and sediment transfer processes of Cd, Pb and Zn in order to better understand the conditions favorable to their bioavailability in Lomé lagoon system.

For this study, an experimental set-up in batch tests was chosen: the first test (Ads: adsorption test) aimed to study the behavior of sediments versus Cd, Pb and Zn in artificial lagoon water (pH and dissolved salts close to those of Lomé lagoon system water), and the second (Des: desorption test) consisted of the remobilization of Cd, Pb and Zn in a molar solution of ammonium acetate (CH_3COONH_4).

2 Materials and methods

2.1. Sediment sampling

Four samples of surface sediments were collected by dipping into the Lomé lagoon system using a manual sampler consisting of tubes 40 cm long and 7 cm in diameter vertically embedded in the sediment. Samples of surface sediments taken from plastic bottles were transported to the laboratory in a cooler and then subjected to various treatments, which consisted of drying in ambient air at about 40 °C, homogenization by reducing the clods, and sieving through 2 mm mesh. The lower fractions were stored in plastic bottles at 20 °C until analysis. Lomé lagoon system (consisting of West Lake, East Lake and Bè Lake) is fed mainly by the rain and runoff water, and by the waters of the various storm basins on the Lomé plateau. This hydrosystem is also exposed to discharges of wastewater of all kind (domestic, artisanal, etc.) through the sanitation networks of the City of Lomé without treatment, and leachates from the dumps. Study sites coordinates and mean depth are shown in Table 1 and aerial representation on Figure 1.

Table 1: Study sites coordinates and Mean Depth

Stations	Sites	Coordinates	Mean Depth
West Lake	Om	6.137424°N ; 1.211155°E	3.5 m
Equilibrium Channel	Cm	6.139444°N ; 1.216944°E	1.5 m
East Lake	Em	6.141944°N ; 1.223333°E	3.0 m
Bè Lake	Bm	6.151666°N ; 1.259166°E	3.5 m

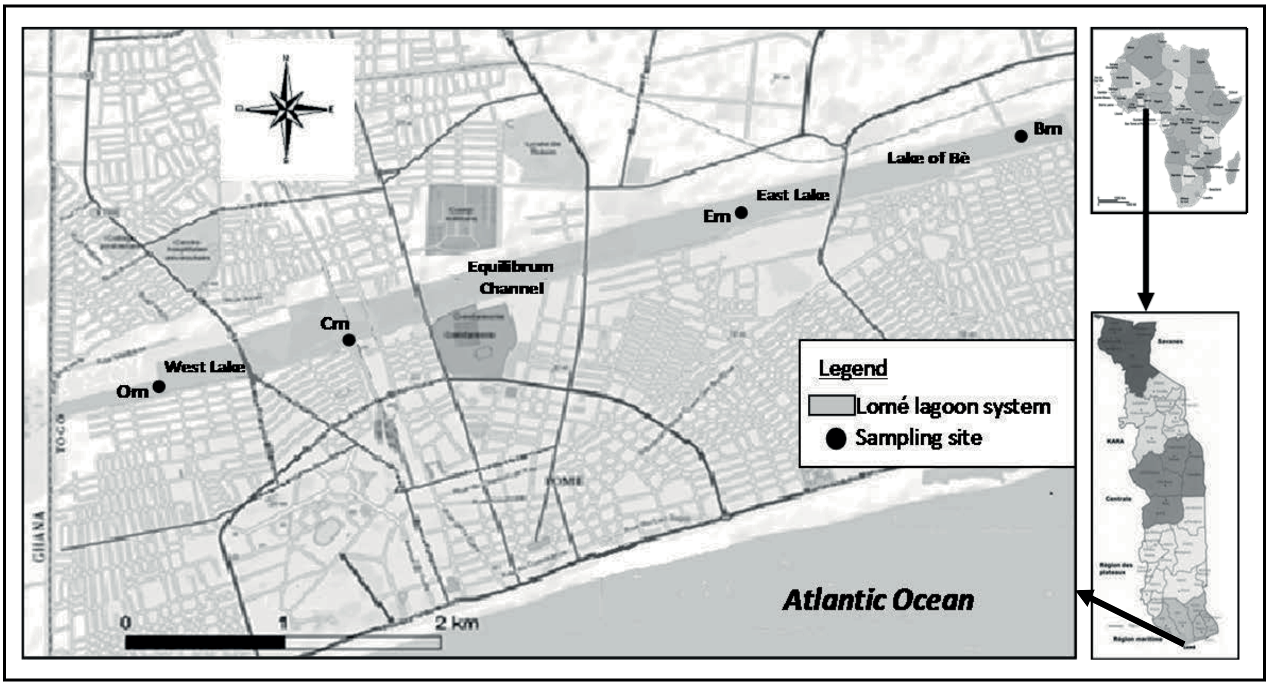

Figure 1: Location of sampling sites

According to the direction of flow of the lagoon system of Lomé during periods of flood, the sampling sites were as follows:

- The West Lake (Om site) is close to an uncontrolled dumpsite, outfalls from storm water collectors, urban wastewaters on the north-western plateau, and the south-western littoral cordon of Lomé, notably Totsi, Avénou, Tokoin west, Akosombo, Casablanca, and Nykonakpoè.
- The Cm site of the Equilibrium Channel is located at the outlet of the large collector of the overflow of storm water, runoff and urban waste water from the Lomé lagoon system, mainly from storm ponds in the districts Agbalépédogan, Aflao-Gakli, Tokoin-Tamé, and Dogbéavou.
- The East Lake Em site, is located at the outlet of the large runoff and urban wastewater collector in the Tokoin-Airport, Witi, Forever, N'kafu, N'Tifafa-Komé, and Bè-Apéyémé.
- Bm site of Lake Bè is situated at the end of the lake of Bè in the extension of a channel of balance between Lake Bè and the fourth lake planned in the port area. Lake Bè receives runoff and urban sewage from neighborhoods Bè, Akodesséwa, Afamé.

For the most analyses, the AFNOR standards on Soil Quality have been used [16, 17]. The similarities of the composition and the physicochemical characteristics between soils and sediments motivated the use of these standards.